3.2 Pesticides

Pesticides have been the fastest growing agricultural production input in the post-World War II era, and have contributed to the relatively high productivity levels of U.S. agriculture. Agricultural production and storage account for about 75 percent of total U.S. pesticide use. Herbicides and insecticides account for most pesticide use, but the recent increase in pounds of pesticide used is mostly for fungicides and other pesticide products applied to high-valued crops. In recent years, agricultural pesticide expenses have increased about 5.5 percent each year, keeping pace with farm production expenses in general. Pesticides have remained about 4 percent of total production expenses during the 1990's and about one-third of the manufactured inputs (fuels, fertilizers, and pesticides).

Contents

- *Pesticide Use on Major Crops 117*
- *Indicators of Potential Pesticide Impact or Risk... 122*
- *Factors Affecting Pesticide Use 125*

Approximately $7.5 billion per year is spent in the United States on agricultural pesticides (USDA, ERS, Aug. 1996). Herbicides account for about two-thirds of the agricultural expenditures for pesticides while insecticides account for about one-fifth (Aspelin, 1994). (See "Glossary" for definitions of terms.)

Pesticide use has engendered concerns about health risks from residues on food and in drinking water and about the exposure of farmworkers when mixing and applying pesticides or working in treated fields. Pesticide use has also raised concerns about impacts on wildlife and sensitive ecosystems.

Pesticide use has conventionally been measured in pounds of active ingredients applied and acres treated. These measurements are useful for assessing the adoption and intensity of pesticide use, making relative comparisons of use between commodities or production regions, and analyzing the cost of pesticides as a production input. These measurements, however, do not account for changes in the pesticide attributes over time or safety features associated with their use and application. New products and the related changes in intensity of treatment, rather than treatment of additional acres, now account for most pesticide use changes. Product formulation has changed in order to lessen environmental and human health effects, to reduce the development of pesticide-resistant pests, and to provide more cost-effective pest control. Efforts to account for changing risk and productivity in aggregate measures of pesticide use are underway. This chapter reports traditional measures of pesticide use—acres treated and pounds applied—as well as new indicators that attempt to account for some pesticide attributes—toxicity and persistence—that may affect human and environmental health.

Table 3.2.1—Overall pesticide use on selected U.S. crops by pesticide type, 1964-1995[1]

Commodities	1964	1966	1971	1976	1982	1990	1991	1992	1993	1994	1995
					1,000 pounds of active ingredients						
Herbicides	48,158	79,384	175,668	341,390	430,345	344,638	335,177	350,534	323,510	350,449	323,791
Insecticides	123,304	119,240	127,709	131,730	82,651	57,392	52,828	60,047	58,096	67,896	69,599
Fungicides	22,167	23,237	29,308	26,632	25,219	27,762	29,439	34,922	36,583	43,059	44,804
Other pesticide	21,379	18,747	31,710	30,741	34,232	67,900	79,451	90,019	97,810	129,639	127,445
Total on selected crops	215,008	240,608	364,395	530,493	572,448	497,693	496,895	535,522	515,999	591,044	565,639
					1,000 cropland acres						
Area represented	174,552	175,040	190,638	233,221	255,866	228,508	226,021	231,531	226,586	232,804	227,855
Total cropland used for crops	335,000	332,000	340,000	340,800	383,000	341,000	337,000	338,000	330,000	338,500	338,000
					Pounds of active ingredient per planted acre						
Herbicides	0.276	0.454	0.921	1.464	1.682	1.508	1.483	1.514	1.428	1.505	1.421
Insecticides	0.706	0.681	0.670	0.565	0.323	0.251	0.234	0.259	0.256	0.292	0.305
Fungicides	0.127	0.133	0.154	0.114	0.099	0.121	0.130	0.151	0.161	0.185	0.197
Other pesticides	0.122	0.107	0.166	0.127	0.134	0.297	0.352	0.389	0.432	0.557	0.559
Total on selected crops	1.232	1.375	1.911	2.275	2.237	2.178	2.198	2.313	2.277	2.539	2.482
Percent of crop area represented[2]	52	53	56	68	67	67	67	69	69	69	67

[1] Estimates include corn, soybeans, wheat, cotton, potatoes, other vegetables, citrus fruit, apples, and other fruit.
[2] Share of total for the selected crops to total cropland used for crops.
Source: USDA, ERS, AER-717 (prior to 1993); unpublished USDA survey data (following 1993).

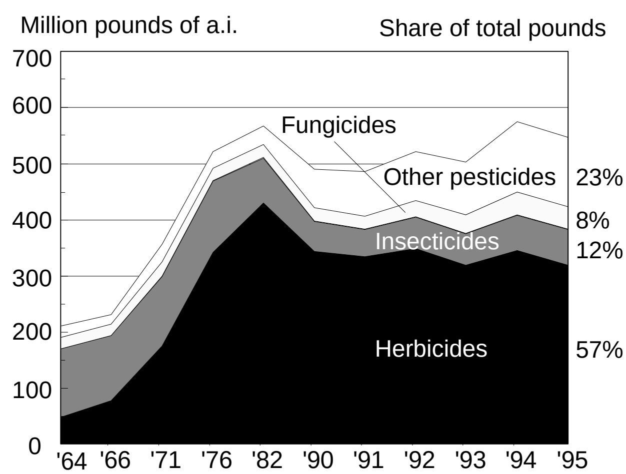
Pesticide Use on Major Crops

Synthetic pesticides were initially developed for commercial agricultural use in the late 1940's and 1950's and were widely adopted by the mid-1970's. USDA's benchmark surveys of pesticide use by farmers show that the quantities applied to major field crops, fruits, and vegetables first peaked in 1982 (fig. 3.2.1 and table 3.2.1). The crops included in the surveys—corn, cotton, soybeans, wheat, fall potatoes, other vegetables, citrus, apples, and other fruit—account for about 67 percent of the current cropland used for crops. Pesticide use on these crops grew from 215 million pounds in 1964 to 572 million pounds in 1982. This increase can be attributed to three factors: increased planted acreage, greater proportion of acres treated with pesticides, and higher application rates per treated acre. (More detail on proportions of acres treated, application rates, and pest management practices can be found in chapter 4.4, *Pest Management*.)

Pesticide use declined between the 1982 and 1990 benchmark surveys as commodity prices fell and large amounts of land were taken out of production by Federal programs.

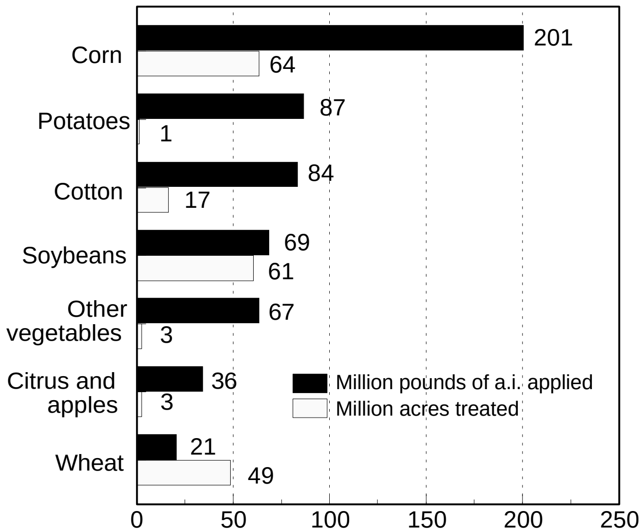
Since 1990, total quantities of pesticides have generally increased, but continue to fluctuate with changes in planted acreage, infestation levels, adoption of new products, and other factors. An estimated 565 million pounds of pesticides were applied to major field crops and most fruits and

Figure 3.2.1--Total pesticide use on major crops, 1964-95



Includes corn, cotton, soybeans, wheat, potatoes, other vegetables, citrus, and apples, and other fruit (about 67 percent of U.S. cropland).
Source: USDA, ERS estimates.

Figure 3.2.2--Amount of pesticide applied and acres treated, 1995



Source: USDA, ERS estimates

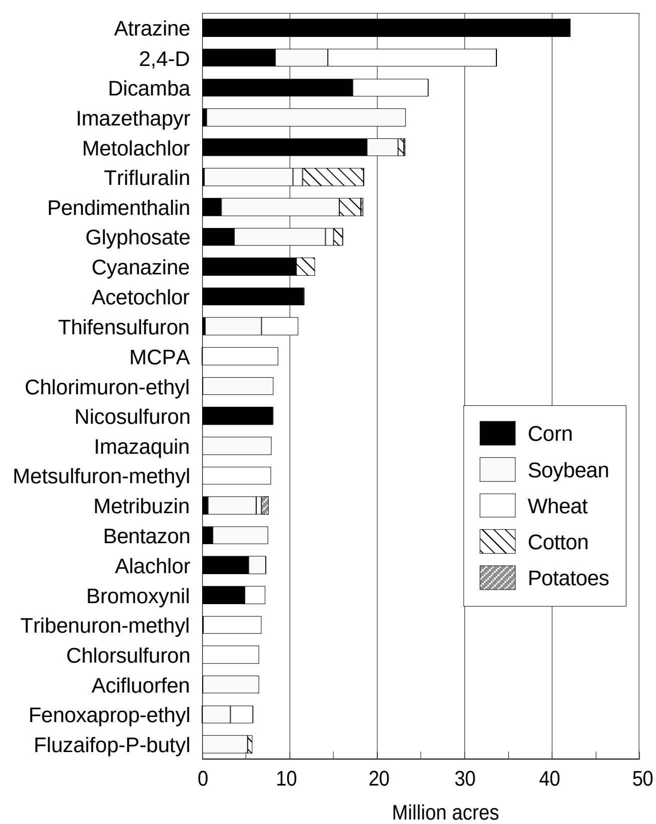
vegetables in 1995, up 13 percent from 1990. Contributing to the increased use was an expanded use of soil fumigants, defoliants, and fungicides on potatoes; expanded cotton acreage; more intensive insecticide treatments of cotton and potatoes; and an increased share of wheat acres treated with herbicides (table 3.2.2). During the same period, the total amount of pesticides applied to corn and soybeans was either unchanged or declined. In 1995, corn received more than double the pesticide amount of any other U.S. crop (fig. 3.2.2). Among the major crops, however, pesticide quantity per acre was by far greatest on fall potatoes.

Herbicides. Herbicides are the largest pesticide class, accounting for 57 percent of pounds of active ingredients in 1995 (table 3.2.1). Weeds compete with crops for water, nutrients, and sunlight, and cause reduced yields. Producers, in managing weeds, must consider infestation levels; weed species resistant to specific ingredients; the effect of treatment on following crops; control of soil weed seed populations; and the labor requirement, cost, and risk of using cultivation or other mechanical methods of weed control. Since 1990, herbicide use has remained relatively unchanged—between 324 million and 350 million pounds (table 3.2.1).

Although many herbicide active ingredients are used in agriculture, a relative few account for most of the use. Atrazine, 2,4-D, and dicamba, all widely used for more than 30 years, still account for the largest treated acreage among major field crops (table 3.2.3, fig. 3.2.3). Atrazine, which remains active in the soil throughout most of the growing season, is used to control many types of weeds in corn and sorghum. The herbicide 2,4-D has been widely used on wheat and corn, and more recently used on soybeans as a preplant application with no-till. Trifluralin, another ingredient available 30 years ago, continues to be the leading herbicide used on cotton and is still widely used on soybeans and many vegetable crops. Since the availability of imazethapyr and some other imidazalinone and sulfonyurea products in the 1980s, trifluralin use, especially on soybeans, has declined.

Insecticides. Insecticides accounted for 12 percent of the total quantity of pesticides applied in 1995 to the surveyed crops (fig. 3.2.1). Damaging insect populations can vary annually depending on weather, pest cycles, cultural practices such as crop rotation and destruction of previous crop residues, and other factors. Insecticide use includes both preventative treatments, which are applied before infestation levels are known, and intervention treatments, which are

Figure 3.2.3--Acres treated with commonly used herbicides, 1995



Source: USDA, ERS 1995 Cropping Practices Survey data.

Table 3.2.2—Estimated quantity of pesticide active ingredient applied to selected U.S. crops, 1964-95[1]

Commodities	1964	1966	1971	1876	1982	1990	1991	1992	1993	1994	1995
					*1,000 pounds of **herbicides***						
Corn	25,476	45,970	101,060	207,061	243,409	217,500	210,200	224,363	201,997	215,636	186,314
Cotton	4,628	6,526	19,610	18,312	20,748	21,114	26,032	25,773	23,567	28,565	32,873
Wheat	9,178	8,247	11,622	21,879	19,524	16,641	13,561	17,387	18,304	20,708	20,054
Sorghum	1,966	4,031	11,538	15,719	15,738	13,485	14,156	na	na	na	na
Rice	2,559	2,819	7,985	8,507	14,089	16,139	16,092	17,665	na	na	na
Soybeans	4,208	10,409	36,519	81,063	133,240	74,400	69,931	67,358	64,092	69,257	68,126
Peanuts	2,894	2,899	4,374	3,366	4,927	4,070	4,510	na	na	na	na
Potatoes	1,297	2,220	2,178	1,764	1,636	2,361	2,547	2,152	2,504	2,866	2,894
Other vegetables	2,194	3,488	3,361	5,419	4,345	4,916	4,712	5,850	5,741	6,137	6,119
Citrus	207	353	546	4,756	6,289	5,652	6,076	5,545	5,086	4,793	4,665
Apples	278	389	156	575	649	396	429	419	445	605	767
Other fruit	692	1,782	615	560	504	1,659	1,690	1,687	1,774	1,882	1,978
					*1,000 pounds of **insecticides***						
Corn	15,668	23,629	25,531	31,979	30,102	23,200	23,036	20,866	18,479	17,349	14,956
Cotton	78,022	64,900	73,357	64,139	19,201	13,583	8,159	15,307	15,429	23,882	30,039
Wheat	891	876	1,712	7,236	2,853	970	208	1,153	152	2,031	910
Sorghum	788	767	5,729	4,604	2,559	1,085	1,140	na	na	na	na
Rice	284	312	946	508	565	161	309	178	na	na	na
Soybeans	4,997	3,217	5,621	7,866	11,621	0	445	359	346	203	515
Peanuts	5,518	5,529	5,993	2,439	1,035	1,726	1,913	na	na	na	na
Potatoes	1,456	2,972	2,770	3,261	3,776	3,591	3,597	3,514	3,943	4,459	3,109
Other vegetables	8,290	8,163	8,269	5,671	4,465	4,709	4,466	5,482	5,305	5,591	5,573
Citrus	1,425	2,858	3,049	4,604	5,306	2,811	3,977	4,538	5,271	5,110	5,143
Apples	10,828	8,494	4,831	3,613	3,312	3,691	4,013	3,909	4,150	3,846	3,564
Other fruit	1,727	4,131	2,569	3,361	2,016	4,837	4,928	4,919	5,023	5,424	5,789
					*1,000 pounds of **fungicides***						
Corn	0	0	0	20	69	0	0	0	0	0	19
Cotton	171	376	220	49	200	988	701	785	684	1,065	1,045
Wheat	0	0	0	862	1,088	172	73	1,154	688	1,012	500
Sorghum	0	0	0	0	0	0	0	na	na	na	na
Rice	0	0	0	0	80	194	426	388	na	na	na
Soybeans	0	0	0	176	71	0	0	85	0	45	13
Peanuts	1,106	1,108	4,431	6,834	4,739	7,321	8,114	6,725	na	na	na
Potatoes	3,229	3,531	4,124	4,168	4,031	2,808	3,172	3,616	4,369	6,358	7,973
Other vegetables	4,530	4,093	5,667	5,051	6,692	12,917	13,126	17,260	18,715	21,880	21,810
Citrus	4,929	4,056	9,257	5,897	4,881	2,555	3,598	3,429	3,322	3,582	4,019
Apples	7,750	8,496	7,207	6,489	5,667	4,177	4,544	4,377	4,599	4,627	4,680
Other fruit	1,558	2,685	2,833	3,921	2,520	4,146	4,224	4,216	4,206	4,491	4,745
					*1,000 pounds of **other pesticides***						
Corn	76	546	443	483	130	0	0	0	0	0	0
Cotton	12,431	14,207	18,696	12,682	9,347	15,188	15,457	15,781	12,658	15,616	19,733
Wheat	0	47	245	0	0	0	0	0	0	0	0
Sorghum	0	40	0	266	44	0	0	na	na	na	na
Rice	0	0	0	0	17	0	0	109	na	na	na
Soybeans	0	49	52	2,030	2,430	0	0	0	0	0	0
Peanuts	6,990	7,005	471	1,188	1,627	2,364	2,620	na	na	na	na
Potatoes	91	9	6,397	8,576	15,188	35,069	45,626	49,671	157,494	79,809	72,928
Other vegetables	5,819	569	3,435	5,061	6,206	17,283	17,998	24,189	27,516	33,400	33,293
Citrus	1,539	681	1,280	214	7	10	15	31	49	108	179
Apples	1,037	1,079	548	574	421	73	73	66	65	79	93
Other fruit	386	1,560	614	1,120	504	276	282	281	27	627	1,221
					*1,000 pounds of **all pesticide types***						
Corn	41,220	70,145	127,034	239,543	273,710	240,700	233,235	245,229	220,476	232,985	201,289
Cotton	95,252	86,009	111,883	95,182	49,497	50,873	50,349	57,646	52,338	69,128	83,689
Wheat	10,069	9,170	13,579	29,977	23,465	17,782	13,842	19,694	19,144	23,751	21,464
Sorghum	2,754	4,838	17,267	20,589	18,341	14,570	15,296	na	na	na	na
Rice	2,843	3,131	8,931	9,015	14,751	16,494	16,827	18,340	na	na	na
Soybeans	9,205	13,675	42,192	91,135	147,362	74,400	70,376	67,802	64,438	69,505	68,655
Peanuts	16,509	16,541	15,268	13,827	12,327	15,482	17,157	na	na	na	na
Potatoes	6,073	8,732	15,470	17,769	24,631	43,830	54,942	58,953	68,309	93,492	86,904
Other vegetables	20,833	16,313	20,732	21,202	21,707	39,824	40,302	52,781	57,277	67,008	66,795
Citrus	8,100	7,948	14,132	15,471	16,483	11,028	13,666	13,544	13,729	13,594	14,006
Apples	19,893	18,458	12,742	11,251	10,049	8,337	9,059	8,771	9,260	9,157	9,104
Other fruit	4,364	10,158	6,631	8,963	5,544	10,919	11,123	11,103	11,030	12,424	13,734

[1] Estimates are constructed for the total U.S. acreage of the selected commodities. In years when the surveys did not include all states producing the crop, the estimates assume similar use rates for those States. Petroleum distillates are excluded. Source: USDA, ERS, AER-717 (prior to 1993), and unpublished USDA survey data following 1993.

Table 3.2.3—Herbicide active ingredients used on field crops, major producing States, 1990-95[1]

Active ingredient	1990	1991	1992	1993	1994	1995
				1,000 pounds		
Atrazine	45,144	44,439	46,203	41,878	45,586	38,611
Metolachlor	36,834	42,473	42,188	41,411	46,787	37,142
Cyanazine	22,024	24,118	27,238	27,367	29,519	24,066
Acetochlor	0	0	0	0	7,314	22,586
Trifluralin	17,892	18,426	16,585	13,975	13,722	13,392
Pendimethalin	8,779	10,595	11,303	12,685	13,702	16,024
2,4-D	9,055	6,800	7,753	10,962	12,207	12,266
Alachlor	41,476	45,992	45,146	36,561	27,270	11,144
EPTC	28,671	15,222	11,269	11,881	7,473	8,238
Glyphosate	1,963	3,048	2,606	5,809	6,491	8,117
Dicamba	4,488	3,803	5,307	5,051	7,098	6,139
Bentazon	4,910	3,889	4,414	3,969	4,959	4,364
MCPA	2,496	2,286	2,608	2,447	2,971	3,030
Butylate	10,510	5,975	5,979	3,850	2,117	1,609
Metribuzin	2,959	2,537	1,975	2,003	1,773	1,498
Imazethapyr	290	649	764	918	1,083	1,329
Sethoxydim	397	483	546	468	588	625
Imazaquin	607	541	589	617	758	564
Chlorimuron-ethyl	199	173	139	143	129	118
Other herbicides[2]	40,173	35,297	33,682	33,336	27,207	27,105
All herbicides	264,050	254,154	253,742	244,070	257,754	237,967
				1,000 acres treated		
Atrazine	37,513	39,485	43,509	39,037	42,909	36,130
2,4-D	23,831	18,929	22,353	29,866	32,340	31,549
Dicamba	17,735	15,886	22,197	22,367	28,487	24,875
Imazethapyr	5,328	11,679	14,321	16,214	19,425	22,837
Metolachlor	19,539	22,307	22,617	22,078	24,328	19,452
Trifluralin	23,556	23,089	21,425	18,367	18,146	17,064
Pendimethalin	9,123	11,437	13,216	13,788	14,450	16,412
Glyphosate	3,626	5,962	6,043	11,848	12,911	14,971
Cyanazine	13,206	14,164	15,724	14,531	15,150	12,414
Acetochlor	0	0	0	0	4,103	11,284
MCPA	7,220	6,852	7,884	7,670	8,547	8,038
Bentazon	8,146	6,629	7,656	6,246	8,038	7,070
Chlorimuron-ethyl	8,339	7,509	7,461	7,232	6,787	6,633
Imazaquin	5,262	5,771	6,623	6,322	7,794	6,353
Alachlor	21,044	22,535	22,307	17,744	13,766	6,348
Metribuzin	8,924	7,706	6,705	6,437	5,811	5,892
Sethoxydim	2,255	2,643	3,079	2,591	3,228	3,532
EPTC	6,504	3,684	2,634	2,988	1,855	2,137
Butylate	2,715	1,564	1,439	1,021	630	465

[1] Represents planted area of corn (10 States), soybeans (8 States), cotton (6 States), winter wheat (11 States), spring and durum wheat (4 States), and fall potatoes (11 States). For States included, see "Cropping Practices Survey" in the appendix. For these crops, the area represented in 1995 was about 165 million acres, 75 percent of total planted acres of these crops.

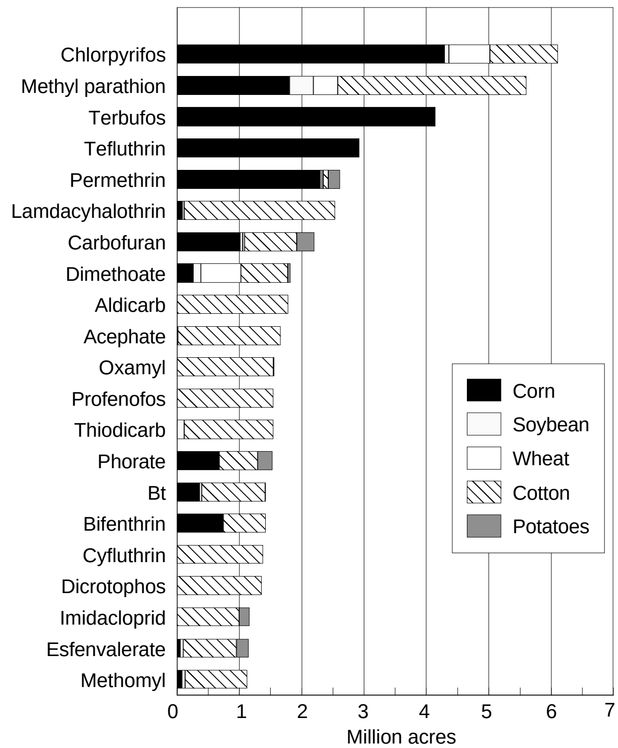
[2] Total pounds of all other herbicides used. No single ingredient in any year exceeded 5 million pounds.

Source: USDA, ERS, Cropping Practices Surveys, 1990 to 1995.

based on monitored infestation levels and expected crop damages. While the quantity of insecticides applied has increased in recent years, the amount is down significantly from the 1960's and early 1970's (table 3.2.1). The drop from earlier years is primarily due to the replacement of organochlorine insecticides, used prior the 1970's, with other insecticides that can be applied at much lower rates. The 69.4 million pounds of insecticide applied in 1995 was about half the quantity used in 1976 and earlier years. Since 1990, insecticide use has declined on corn (with fewer acres treated) but increased on cotton (with expanded area and more intensive treatments per acre) (table 3.2.2).

Three insecticide active ingredients (chlorpyrifos, methyl parathion, and terbufos) account for 43 percent of insecticides used on the five major field crops (fig. 3.2.4, table 3.2.4). Chlorpyrifos was the most used insecticide on corn, second most used on wheat, and applied to 9 percent of the cotton acreage. It is used to treat corn rootworm larvae, cutworms, Russian wheat aphid, and bollworms. Methyl parathion is used mostly on cotton to treat boll weevil and other cotton insects while terbufos is used for corn insects.

Figure 3.2.4--Acres treated with commonly used insecticides, 1995



Source: USDA, ERS 1995 Cropping Practices Survey data.

Fungicides. Fungicides are applied to fewer acres than are herbicides and insecticides and account for the smallest share of total pesticide use (table 3.2.1). Fungicides are mostly used on fruits and vegetables to control diseases that affect the health of the plant or quality and appearance of fruit. The 44.6 million pounds estimated for 1995 is up 21 percent from 1993 and 61 percent from 1990. A large share of this increase is attributed to diseases on potatoes and other vegetables. Several common fungicides used to treat potatoes for early and late blight (chlorothalonil, mancozeb, metalaxyl, and copper hydroxide) had a 40 to 400 percent increase in use over this period. Some cotton and wheat acres are treated for diseases, but these treatments account for only a small share of total fungicide use.

Other pesticides. Pesticides designated as "other," which include soil fumigants, growth regulators, desiccants, and harvest aids, had the largest increase in use of any of the pesticide classes (table 3.2.1, fig. 3.2.1). The use of these pesticides, whose function is not necessarily to destroy a pest organism, increased about 17 percent each year since 1990 and accounts for about 23 percent of the total pounds of all active ingredients applied to the surveyed crops. Growth regulators, desiccants, and harvest aids, normally applied at low rates, are used to affect the branching structure of plants, to control the time of maturity or ripening, to aid mechanical harvesting, to defoliate plants before harvest, and to alter other plant functions to improve quality or yield. Fumigants, normally applied at very high application rates, are used mostly on vegetable root crops susceptible to damage from soil nematodes and other soil organisms. Fumigants and some desiccants, with application rates that often exceed 200-300 pounds per acre, account for most of the quantity of pesticides in this class but only a small share of the area treated. Small changes in the use of such products, when averaged with other products applied at only a few pounds or less per acre, can grossly affect the significance of the overall change in pesticide use. USDA reports (NASS, 1991-96) show that the increase of 3 fumigants (methyl bromide, metam sodium, and dichloropropene) account for most of the increase in pesticide quantity between 1990 and 1995 but were applied to a relatively small share of the acres.

Table 3.2.4—Insecticide active ingredients used on field crops, major producing States, 1990-1994[1]

Active ingredient	1990[2]	1991	1992	1993	1994	1995
			1,000 pounds			
Chlorpyrifos	5,511	7,141	6,382	6,242	6,370	5,933
Methyl parathion	531	2,421	3,837	4,794	7,429	5,996
Terbufos	8,831	5,331	5,528	4,571	4,290	3,268
Phorate	2,787	2,531	2,005	2,549	2,127	1,830
Profenofos	.	322	1,276	1,326	1,875	1,742
Carbofuran	1,773	1,803	1,207	720	748	1,290
Aldicarb	44	559	564	637	938	1,140
Fonofos	2,652	2,888	2,121	1,837	1,628	844
Methomyl	0	183	269	382	240	580
Dimethoate	165	307	483	639	619	484
Esfenvalerate	18	73	81	47	56	302
Permethrin	104	318	185	146	274	247
Carbaryl	255	164	131	56	186	218
Other insecticides[3]	4,620	7,999	8,910	8,922	12,045	11,313
All insecticides	26,705	30,567	31,271	31,107	36,341	35,187
			1,000 acres treated			
Chlorpyrifos	4,467	6,468	6,340	5,835	6,457	5,753
Methyl parathion	1,255	3,104	3,834	3,964	5,078	4,881
Terbufos	7,847	4,855	5,083	4,293	4,050	3,139
Permethrin	812	2,826	1,598	1,190	2,459	2,226
Carbofuran	1,751	2,030	1,371	863	1,082	1,825
Aldicarb	17	1,033	1,030	1,164	1,532	1,784
Profenofos	363	993	1,227	1,532	2,400	1,543
Phorate	1,918	1,638	1,550	1,981	1,810	1,513
Dimethoate	576	989	1,674	1,276	2,016	1,504
Esfenvalerate	345	1,560	1,228	703	773	1,011
Methomyl	0	636	723	778	613	1,077
Fonofos	2,569	2,646	1,789	1,813	1,504	895
Carbaryl	370	370	176	73	167	137

[1] Represents planted area of corn (10 States), soybeans (8 States), cotton (6 States), winter wheat (11 States), spring and durum wheat (4 States), and fall potatoes (11 States). For States included, see "Cropping Practices Survey" in the appendix. For these crops, the area represented in 1995 was about 165 million acres, 75 percent of total planted acres of these crops.

[2] Does not include insecticides applied to cotton.

[3] Total pounds of all other herbicides used. No single ingredient in any year exceeded 1 million pounds.

Source: USDA, ERS, Cropping Practices Surveys, 1990 to 1995.

Indicators of Potential Pesticide Impact or Risk

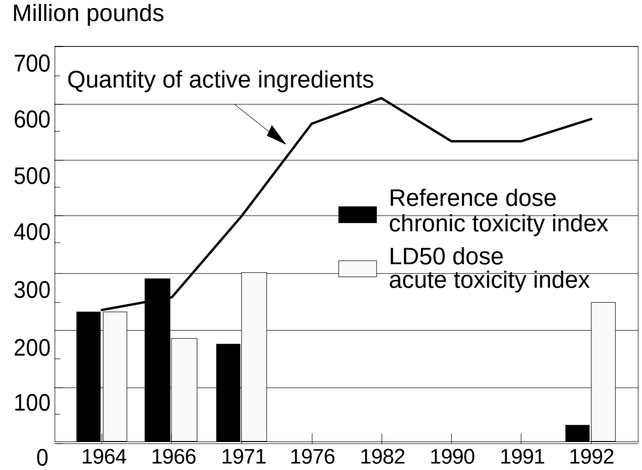
Pesticide use in the United States, as traditionally reported in pounds of active ingredient applied, reached a record level in 1994 (table 3.2.1). However, pesticide weight, as a measure of use, has two particularly notable drawbacks when evaluating the potential for harm to human health and the environment. First, the more than 350 pesticide active ingredients used in U.S. agricultural production in the last 40 years vary widely in terms of toxicity per unit of weight, irrespective of the scale used to measure toxicity.[1] Second, weight does not account for the persistence of the pesticide in the environment. The longer a pesticide ingredient remains active in the environment, the more potential there is for it to come in contact with non-target species. Persistence varies widely between active ingredients, but many modern pesticides have half-lives (the typical measure of persistence) of 10-100 days in the fields where they are applied. This is significantly less than some organochlorine products banned from use in the 1970's, which had half-lives as high as 30 years.

Many new pesticide ingredients are applied at lower rates (in ounces rather than pounds per acre) and are

[1] There are numerous measures of toxicity for individual pesticide active ingredients, including those designed to measure chronic and acute toxicity to humans, and toxicities to various avian, aquatic, and beneficial insect species. The relative toxicity of each pesticide ingredient varies depending upon which measure is used; for a given measure, there is wide variation in toxicity among pesticide ingredients.

less persistent in the environment. In addition, many (formerly) widely used, but highly toxic and persistent, ingredients have been restricted or banned by the Environmental Protection Agency. In order to account for these differences in exposure and toxicity, adjustment factors were used to convert historic pesticide-use data (published in terms of pounds applied) into indicators of risk that are more meaningful with respect to potential environmental or health impacts. The adjustment creates a common denominator that accounts for variation in toxicity and persistence among individual pesticide ingredients. Thus, the amount of each pesticide active ingredient applied is aggregated in common units that are consistent across time, regions, pesticide types, toxicity, and persistence. Other researchers have created indexes using related methodology to make assessments of aggregate changes in pesticide toxicity (Kovach and others, 1992; Levitan and others, 1995).

Figure 3.2.5--Comparison of indicators of pesticide use and risk



Source: USDA, ERS, based on USDA, 1960; USDA, 1968; USDA, 1974; Gianessi, 1995.

The potential risk indicators are based on indexes of the combined toxicity and persistence of each individual ingredient. (See box, "Estimating Pesticide Impact or Risk.") The indexes are created by calculating the number of units (Reference Dose or LD50) contained in 1 pound of each pesticide active ingredient and multiplying that value by the estimated number of days (as measured by half-life) that an application of the ingredient remains active in the environment. The calculated index value for each ingredient can be multiplied by the pounds applied and then summed over all ingredients to obtain an aggregate indicator of potential risk.

The analysis first compares pounds of active ingredient applied, then compares two potential risk indicators (table 3.2.5). Both of the risk indicators adjust for persistence, but each employs an alternative measure of toxicity. An indicator of potential chronic risk is based on Reference Dose, which is a measure of long-term (chronic) toxicity. An indicator of potential acute risk is based on the Oral LD50, and measures acute toxicity associated with ingestion of the pesticide.

For most consumers, chronic intake through food and water is the principal health concern stemming from pesticide use in agriculture. A health-risk measure, based on Reference Dose, was chosen to represent this long-term risk to health. The acute measure, based on LD50, is of more interest to farmers, farmworkers, and pesticide applicators who are more prone to acute exposure.

While the total pounds of active ingredients applied in 1992 was up 247 percent from 1964, the total potential chronic risk from the 1992 pesticides was actually less than the risk from the pesticides applied in 1964 (fig 3.2.5). Much of the reduction in the potential chronic risk indicator reflects the removal of many organochlorine insecticides, such as aldrin, DDT, chlordane, and toxaphene.

Even with the ban on highly toxic and persistent organochlorine insecticides and other reductions in use, insecticides continue to account for most of the potential risk (table 3.2.5). Insecticides accounted for about 92 percent of the total potential acute risk and more than half of the total potential chronic risk in 1992. While the total potential risk associated with herbicides and fungicides increased 7 to 8 times over the 28-year time period, these pesticide classes still accounted for under 20 percent of the total potential chronic risk and 5 percent of the total potential acute risk in 1992. The potential chronic risk from all other classified pesticides—mostly soil fumigants—increased about 75 percent in this period and accounted for over 30 percent of the total potential chronic risks in 1992.

The results also suggest that when toxicity is defined in acute terms, potential risk from pesticide application may be slightly greater in 1992 than it was in 1964. The acute measure may be most meaningful to farmers, pesticide applicators, and farmworkers, all of whom have higher probabilities of acute exposure. However, the Environmental Protection Agency and State agencies have instituted a number of farmworker safety regulations (protective clothing, enclosed application systems, field re-entry

Estimating Pesticide Impact or Risk

Impact or risk from pesticides can be estimated from some combination of toxicity and exposure factors. Ideally, procedures and estimated measurements used to account for the potential environmental and human-health impacts of pesticide applications would include factors related to mobility of pesticides, persistence in the environment, exposure route (proportion of pesticide likely to enter the air, run off in surface water, adhere to sediment, percolate into ground water, and remain as residue on food), toxicity to each of many species, and size of the populations potentially subject to exposure. Toxicity varies by species, and varies depending upon whether the exposure is chronic or acute. Likewise, persistence is not an inherent characteristic of a pesticide active ingredient, but varies with temperature, moisture, and exposure to sunlight and to microbial degradation. Further, the data generally available on persistence are for the first soil half-life, which itself is but one indicator of persistence, and are not necessarily equal to subsequent half-lives. The amount of pesticide in runoff, leachate, and soil particles depends not only on the amount of rainfall, but its intensity and the interval between pesticide application and the occurrence of the rain. Each of these factors is occurrence-specific.

A system capable of accounting for all of these factors cannot be realistically constructed, especially for large areas. Data requirements would be prohibitive, and the relevance of the measure would be site-specific, unsuitable for analysis of trends on a national scale. Even if the volume of data could be modeled and managed, measures of relevant attributes do not exist for many of the more than 350 pesticide active ingredients that have been used as inputs to agricultural production over the past several decades.

The risk indicators reported here are a simplified calculation of pesticide risk, developed to be workable for analysis of historical trends at the national level. Other researchers have created indexes using related methods to conduct pesticide impact assessments for other purposes, relying on less aggregate analysis (Kovach and others, 1992; Levitan and others, 1995). By necessity, many relevant environmental and safety factors are not taken into account in the estimates reported here making these indicators less than ideal. Nevertheless, these risk indicators are superior to the information contained in data on pounds applied or acres treated. To emphasize the abstraction of this indicator from variation that exists in the real world, we view the indicators as a measure of the “potential” impact from pesticide use.

The Chronic risk index was created by combining Reference Dose as the indicator of chronic toxicity and soil half-life as an indicator of potential exposure. Use of Reference Dose implies that the units relate to human health, and may not necessarily be useful indicators of potential impact on other species. For active ingredients for which it was available, the EPA’s Reference Dose measure was used. If that measure was not available, a Reference Dose estimate from the Office of Pesticide Programs (EPA), characterized by less rigorous review, was substituted. Lacking either of those indicators of toxicity for some active ingredients, estimates reported by the World Health Organization were used. Averages for the active ingredient’s chemical family were used in other cases. Using Reference Dose does not take into account carcinogenic potential that is built into other health measures from the EPA, such as health advisory levels and maximum contaminate levels. These latter measures are available only for a very limited number of active ingredients, however.

The soil half-life measures are taken from databases constructed by the Agricultural Research Service. As such, the indicators for each active ingredient are midpoints of the range of soil half-lives reported in the literature, which in turn are based on estimates derived under a variety of soil, moisture, and temperature conditions.

The acute risk index was created by combining an Oral LD50 measure of toxicity and the same soil half-life measure of potential exposure. Where available, the Oral LD50 for rats was used. For some active ingredients, this measure was not available, and an Oral LD50 for a related mammal, usually mice, was substituted. This procedure is less than ideal in that acute toxicity varies widely among species. No adjustment was made to translate the rat LD50 into human terms. The Oral LD50 is a severe threshold, implying the ingestion of an amount of active ingredient sufficient to kill 50 percent of the treated animals. Such a severe level of exposure is unlikely in reality. Despite its limitation, Oral LD50 for rats or related mammals should provide a relative indicator of risk to humans and other species from acute exposure. EPA has developed less severe indicators in the form of 1- and 10-day health advisory levels, but they are available only for a limited number of active ingredients.

Table 3.2.5—Indicators of pesticide use and risk on major crops, selected years 1964-92[1]

Pesticide type	Measures[2]	1964	1966	1971	1992
		Percent of total pesticides			
Herbicides	pounds a.i.	23.58	34.26	49.83	67.30
	chronic risk indicator	0.21	0.27	0.93	15.26
	acute risk indicator	0.77	1.40	1.85	4.93
Insecticides	pounds a.i.	55.07	47.74	34.52	10.13
	chronic risk indicator	97.72	97.97	95.45	54.04
	acute risk indicator	91.32	94.82	88.84	91.76
Fungicides	pounds a.i.	9.33	8.49	7.74	6.57
	chronic risk indicator	0.05	0.06	0.08	2.95
	acute risk indicator	0.01	0.03	0.02	0.09
Other pesticides	pounds a.i.	12.02	9.50	7.91	16.00
	chronic risk indicator	2.02	1.70	3.53	30.75
	acute risk indicator	7.89	3.75	9.29	3.22
		Index: 1964 = 100			
Herbicides:	pounds a.i.	100	159	362	706
	chronic risk indicator	100	163	344	838
	acute risk indicator	100	145	283	705
Insecticides:	pounds a.i.	100	95	107	45
	chronic risk indicator	100	125	75	5
	acute risk indicator	100	382	115	111
Fungicides:	pounds a.i.	100	100	142	174
	chronic risk indicator	100	133	120	648
	acute risk indicator	100	179	160	744
Other pesticides:	pounds a.i.	100	87	113	329
	chronic risk indicator	100	105	134	173
	acute risk indicator	100	38	139	45
Total pesticides:	pounds a.i.	100	109	171	247
	chronic risk indicator	100	125	76	11
	acute risk indicator	100	80	118	110

[1] Estimates include corn, soybeans, wheat, cotton, sorghum, rice, peanuts, potatoes, other vegetables, citrus, and apples. See table 3.2.2 for pesticide quantities. [2] See glossary for definitions. Source: USDA, ERS, preliminary estimates.

intervals, and training) to reduce farmworkers' exposure to pesticides.

Factors Affecting Pesticide Use

Prior to the development of synthetic pesticides following World War II, a farmer's solution to weed, insect, and disease problems was primarily the use of physical and cultural practices. Weeds were controlled by tillage, mowing, site selection, crop rotation, use of seeds free of weedseeds, and hoeing or pulling by hand. Insect pests and diseases were controlled through seed selection, crop rotations, adjustment of planting dates, and other cultural practices, but the risk of severe infestations, yield losses, and even abandoned production was still ever-present.

Between 1950 and 1980, chemical pest control was widely adopted on most crops (table 3.2.2). Public and private research introduced new pesticides (and other innovations) that could increase yields and substitute for some farm labor, machinery, and fuel. Higher prices for energy and other manufactured inputs along with rising wage rates promoted this trend. By 1980, herbicide use climbed toward 100 percent of the acreage of corn, soybeans, cotton, and many other crops. Insecticides and other pesticides were also widely used.

Although the adoption of pesticides as a crop production technology was nearly complete by the mid 1970's, many factors continue to affect the use of pesticides. Changes in planted acres or shifts in production between commodities and regions can affect the number of acres treated and applied quantities. Pest cycles and annual fluctuations caused by weather and other environmental conditions often determine whether infestation levels reach treatment thresholds. Changes in pesticide regulations, prices, new products, and pest resistance to pesticides also affect the producer's selection of active ingredients, application rates, and methods of treatment. (See chapter 4.4, *Pest Management* for more information.)

Federal Agricultural Programs

Federal commodity and conservation programs provide mixed incentives to both increase and decrease pesticide use. Acreage restrictions and set-aside provisions in past commodity programs and the Conservation Reserve Program reduced planted acreage and, hence, pesticide use on those acres that otherwise would have been in production. Pesticide use dropped in 1983 with the large feedgrain acreage idled under the payment-in-kind program (PIK) and has subsequently paralleled other major changes in planted acreage (Aspelin, 1994). On the other hand, Federal programs can provide incentives to increase pesticide use on the land that is not set aside. When planted acreage was constrained and price expectations included program payments, producers tended to substitute nonland inputs, including fertilizer and pesticide, to boost yields and capture higher returns on their eligible planted acreage. Participants in Federal commodity programs used higher nitrogen fertilizer and herbicide application rates than producers who did not participate (Ribaudo and Shoemaker, 1995).

The Federal Agriculture Improvement and Reform Act of 1996 removes the link between income support payments and current farm production and will likely remove most incentives for producers to substitute yield increasing inputs per acre of planted land. However, producers' greater planting flexibility could lead to increased pesticide use as idled land returns to production. Producers are now permitted to plant 100 percent of their total base acreage plus additional acreage to any crop (with some exceptions for fruits and vegetables) without loss of Federal subsidy.

Pesticide Prices

Aggregate pesticide use is negatively related, but relatively unresponsive, to changes in pesticide prices (Fernandez-Cornejo, 1992; McIntosh and Williams, 1992; and Oskam and others, 1992). That is, the percentage change in quantity of pesticide use is relatively less than the percentage change in the price of pesticides. Given the evidence that pesticide demand is relatively unresponsive to pesticide price changes, along with relatively small annual pesticide price changes over the last several years, we would expect that pesticide use, in general, has been largely unaffected by prices.

While overall pesticide use may not be very responsive to small price changes, individual product use can vary from year to year. When different pesticide products are perfect or near-perfect substitutes, small price changes can result in significant changes in the mix of products used as farmers attempt to maximize profits. Pesticide prices, as measured by the agricultural chemicals price index, increased 2-5 percent annually from 1991 to 1995 (table 3.2.6). In total over the 1991-95 period, herbicide prices increased about 12 percent while fungicide prices rose nearly 16 percent, and insecticide prices showed a 19-percent increase. Fungicide prices, which ranged from a 2-percent annual decline (1993-94) to a 7-percent annual increase (1994-95), were the most variable.

Reflecting the price changes and increased use, pesticide expenditures for all farm uses increased about 2 to 7 percent annually over 1991-95 (USDA, Aug. 1996). Pesticide costs per acre for cotton, soybeans, and wheat remained relatively unchanged between 1991 and 1995, but the pesticide costs for corn increased about 4 percent each year. Pesticide costs for corn edged over $25 per acre in 1994, accounting for 13 percent of total fixed and variable cash production expenses. Pesticide expenditures on cotton, with the largest cost for insecticides, were about $50 per acre and accounted for 15 percent of cash production expenses. Pesticide costs on soybeans ($24 per acre) accounted for 13 percent of cash production expenses while costs on wheat ($6 per acre) accounted for 8 percent.

Index numbers are useful aggregate measures for monitoring price changes, but indexes can mask movements in individual components of the index. Common pesticide active ingredients showed different price trends between 1991 and 1995 (table 3.2.6). These price changes typically reflect shifts in factors such as cost of manufacturing and distribution, price of competing products, patent protection, and planted acreage of the treated crop.

Among insecticides, carbaryl, methyl parathion, and phorate had price increases of 25 percent or more.

Table 3.2.6—Selected April pesticide prices, 1991-1995

Active ingredient	1991	1992	1993	1994	1995	1991-92	1992-93	1993-94	1994-95	1991-95
	Dollars per pound of active ingredient					*Annual percent change*				
Insecticides:										
Aldicarb	22.20	na	22.07	24.67	24.33	na	na	11.8	-1.4	9.6
Carbaryl	4.44	4.95	5.36	5.41	5.74	11.5	8.3	0.9	6.0	29.3
Carbofuran	10.40	10.87	12.20	12.80	12.73	4.5	12.3	4.9	-0.5	22.4
Chlorpyrifos	10.65	11.30	12.03	12.10	12.33	6.1	6.4	0.6	1.9	15.7
Dimethoate	na	11.12	11.05	9.70	10.11	na	-0.7	-12.2	4.2	
Esfenvalerate	187.88	192.42	200.00	210.61	219.70	2.4	3.9	5.3	4.3	16.9
Methomyl	21.44	21.60	22.43	24.14	24.36	0.8	3.8	7.6	0.9	13.7
Methyl parathion	5.10	5.35	5.83	5.98	6.83	4.9	8.9	2.6	14.2	33.8
Permethrin	45.94	46.88	48.13	47.81	48.13	2.0	2.7	-0.6	0.7	4.8
Phorate	7.80	8.05	8.80	9.15	9.90	3.2	9.3	4.0	8.2	26.9
Fungicides:										
Benomyl	31.60	32.60	34.00	35.80	36.00	3.2	4.3	5.3	0.6	13.9
Captan	5.12	5.74	5.96	6.16	6.62	12.1	3.8	3.4	7.5	29.3
Chlorothalonil	7.30	8.04	8.63	8.67	8.75	10.2	7.4	0.4	1.0	19.9
Iprodione	40.40	43.60	45.60	46.60	46.00	7.9	4.6	2.2	-1.3	13.9
Mancozeb	3.54	3.79	3.94	3.87	4.01	7.3	3.7	-1.6	3.7	13.5
Maneb	3.13	na	3.24	3.16	3.38	na	na	-2.3	6.7	8.0
Metalaxyl	74.50	74.00	76.50	81.00	85.00	-0.7	3.4	5.9	4.9	14.1
Sulfur	0.73	0.69	0.53	0.39	0.37	-4.3	-24.2	-26.0	-5.4	-49.3
Triadimefon	108.40	100.00	112.40	115.60	120.20	-7.7	12.4	2.8	4.0	10.9
Ziram	3.24	na	3.61	3.70	3.66	na	na	2.6	-1.1	13.0
Herbicides:										
2,4-D	2.83	2.93	3.20	3.38	3.55	3.5	9.4	5.5	5.2	25.7
Alachlor	6.15	6.35	6.45	6.48	7.03	3.3	1.6	0.4	8.5	14.2
Atrazine	na	2.88	3.15	3.45	3.60	na	9.6	9.5	4.3	
Bentazon	15.38	15.75	16.40	16.98	18.28	2.4	4.1	3.5	7.7	18.9
Chlorimuron	1139.20	1145.60	1152.00	1171.20	1184.00	0.6	0.6	1.7	1.1	3.9
Cyanazine	5.65	5.83	5.95	6.55	7.08	3.1	2.1	10.1	8.0	25.2
Dicamba	17.45	18.18	19.48	19.40	21.88	4.2	7.2	-0.4	12.8	25.4
Glyphosate	13.85	na	13.03	13.40	13.53	na	na	2.9	0.9	-2.3
Imazaquin	134.67	135.33	137.33	140.67	142.67	0.5	1.5	2.4	1.4	5.9
MCPA	3.25	3.25	3.65	3.68	3.98	0.0	12.3	0.7	8.2	22.3
Metolachlor	7.49	7.69	7.79	7.85	8.46	2.7	1.3	0.8	7.8	13.0
Metribuzin	31.73	32.67	34.27	36.27	36.67	2.9	4.9	5.8	1.1	15.5
Pendimethalin	8.85	9.27	9.24	9.12	8.76	4.8	-0.3	-1.3	-4.0	-1.0
Sethoxydim	82.00	76.67	75.33	76.00	74.67	-6.5	-1.7	0.9	-1.8	-8.9
Trifluralin	7.50	8.00	8.08	8.13	8.20	6.7	0.9	0.6	0.9	9.3
Agricultural chemicals price index (1990-92 = 100)	101	103	107	112	115	2.0	3.9	4.7	2.7	13.9
Herbicides	101	102	106	110	113	1.0	3.9	3.8	2.7	11.9
Insecticides	101	104	110	117	120	3.0	5.8	6.4	2.6	18.8
Fungicides & others	101	105	111	109	117	4.0	5.7	-1.8	7.3	15.8

na = not available.
Source: USDA, ERS, based on NASS farm supply dealers annual survey.

These latter three insecticides are widely used on corn as well as several minor fruit and vegetable crops. Most fungicide prices rose over 10 percent, while captan and chlorothalonil increased more than 20 percent. Both captan and chlorothalonil are used extensively on fruit, vegetable, and nut crops such as apples (captan) and peanuts (chlorothalonil) while sulfur (which dropped in price) is heavily applied to grapes.

Among herbicides, the price of sethoxydim dropped while those for 2,4-D, atrazine, cyanazine, dicamba, and MCPA rose. With the exception of MCPA, which is used primarily on wheat and barley, the herbicides with the greatest price increases were extensively used in corn production. However, 2,4-D and dicamba are also used on pasture and wheat land; atrazine is heavily used on corn and sorghum; and cyanazine is a major cotton herbicide.

Pesticide Legislation

The U.S. Environmental Protection Agency (EPA) registers pesticides and ensures they are safe. The Food Quality Protection Act of 1996 defines safe for dietary consumption products as "a reasonable certainty that no harm will result from aggregate exposure" including food, drinking water, and nonoccupational exposures. Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and its amendments, the EPA decides which pesticides are registered and prescribes labeling and other regulatory requirements on their use to prevent unreasonable adverse effects on health and the environment. EPA also regulates pesticides under the Federal Food, Drug, and Cosmetic Act (FFDCA), which requires that tolerances for residues on food and drinking water be established. These tolerances are enforced through monitoring and inspections conducted by the Food and Drug Administration and USDA. (See box, “Pesticide Tolerance and Dietary Risks.")

The Clean Air Act (1970), Clean Water Act (1972), Resource Conservation and Recovery Act (1976), and the Comprehensive Environmental Response, Compensation, and Liability Act (1980) (or Superfund) also contain provisions that apply to pesticide manufacturers that affect their cost of production. The Clean Air Act mandates discharge limits on pollutants, RCRA specifies how to dispose of toxic substances, and the Superfund stipulates who pays for the cleanup of toxic dump sites. All of these regulatory requirements affect the development time and cost of pesticide production. Recent estimates suggest that the research and development of a new

Pesticide Tolerance and Dietary Risks

The Food Quality Protection Act of 1996 sets a consistent safety standard for pesticide use on all foods, and for all health risks. Under the new law, both fresh and processed foods may contain chemical residues at tolerance levels that have been determined to be safe by the EPA. Previously, the largely unenforced "Delaney Clause" of the Federal Food, Drug, and Cosmetic Act prohibited processed foods, but not fresh foods, from containing even trace amounts of carcinogenic chemical residues. The new law contains provisions that "ensure that there is reasonable certainty that no harm will result to infants and children from aggregate exposure." The EPA is required to reassess existing tolerances of all pesticides within 10 years, with priority given to pesticides that may pose the greatest risk to public health.

USDA’s pesticide monitoring by the Agricultural Marketing Service (AMS) measures residues on both domestic and imported samples of fresh fruits and vegetables common in the diets of the U.S. population. The AMS monitoring is used not only to respond to food safety concerns but also to provide the EPA with data to assess the actual dietary risk posed by pesticides. Without actual exposure data, the pesticide registration process assumes all producers apply maximum allowable amounts. This assumed maximum risk may significantly exceed actual risk and jeopardize the registration process for products important to agricultural production. Some pesticide residues were found on 71 percent of the samples in 1993 and 46 percent of the samples in 1994; however, few exceeded established tolerance levels (USDA, AMS, 1996). Of 7,589 samples analyzed in 1994, 4 residue samples exceeded established tolerance and 88 samples had residues where no tolerance was established. Even though the use of DDT has been banned since 1972, 5.5 percent of the 1994 detections were for DDT or its metabolites. Once applied, DDT is slow to degrade in the soil and can continue to occur on crops grown in that soil. The DDT residues were found primarily in root crops and none exceeded tolerance levels. On samples where any pesticide residue was detected, 38 percent were from postharvest pesticide products normally applied to produce to prevent spoilage during storage and transportation.

pesticide takes 11 years and can cost manufacturers between $50 and $70 million (Ollinger and Fernandez-Cornejo, 1995). Results of a study of the impact of pesticide product regulation on innovation and the market structure in the U.S. pesticide industry indicate that regulation encourages the development of less toxic pesticide materials but discourages new chemical registrations, encourages firms to abandon pesticide registrations for minor crops, and favors large firms over smaller ones. Pesticide regulation also encourages firms to develop biological pesticides as an alternative to chemical pesticides (Ollinger and Fernandez-Cornejo, 1995).

States are also active in regulating pesticide use. In 1996, most States had some regulations related to pesticide use in agriculture and/or lawn care, and over half have groundwater laws, posting requirements, and pesticide reporting regulations (Meister Publishing, 1996). Over a third of the States had health advisory levels, containment regulations, and bulk chemical regulations, and 13 States had requirements for reporting pesticide illnesses.

The majority of States also have pesticide registration fees, many of which have increased in the last several years. Nine States tax pesticide products or have other special taxes (Meister Publishing, 1996) that have been used to fund research on pesticide alternatives. For example, the Leopold Center for Sustainable Agriculture, which conducts research on environmentally friendly alternatives, is partially supported from a tax on pesticide and fertilizer sales.

Pesticide Registrations

The EPA registration process requires manufacturers to provide scientific data to substantiate that a proposed product is safe and poses no unreasonable adverse effects to human health or the environment. Tests pertaining to toxicology, reproduction disorders and abnormalities, and potential for tumors from exposure to the pesticide are required. Other required tests evaluate the effect of pesticides on aquatic systems and wildlife, farm worker health, and the environment. The registration process can require up to 70 different types of tests to substantiate the safety of the product. Since 1989, the number of pesticide active ingredients for sale in the United States has decreased by 50 percent and further declines are expected due to reregistration requirements and costs (Pease and others, 1996).

The recently enacted Food Quality Protection Act of 1996 requires periodic re-evaluation of pesticide registrations to ensure that the scientific data supporting registrations remain current. The new law mandates a screening program for estrogenic and other endocrine or synergistic effects and sets a goal for all pesticides to be reviewed and updated on a 15-year cycle. The registration and re-registration process also prescribes those commodities on which the pesticides can be used, at what concentration they can be applied, when and how they are to be applied, and what safety precautions are to be used during and after application. Table 3.2.7 identifies some of the key regulatory action taken against agricultural pesticides and gives the status of special reviews being conducted for reregistration.

The EPA is currently conducting a special review of triazine herbicides (atrazine, cyanazine, and simazine). In 1995, the manufacturers of cyanazine voluntarily withdrew its registration rather than proceed with the special review. Cyanazine, which is identified as a carcinogenic material, is the third most used herbicide on corn and cotton and is also commonly used on sorghum and other crops to control grasses and broadleaf weeds. The manufacturer has agreed to stop selling products containing cyanazine by 1999.

Mevinphos and propargite are insecticides that have been voluntarily canceled by their manufacturers. Mevinphos was canceled for all uses in 1994 due to concerns about acute toxicity and farmworker safety. Because this pesticide degrades quickly after application, it requires only a short interval before harvesting. It was used for aphid control on many fresh fruits and vegetables late in the growing season when other agents could not be applied. Propargite was withdrawn in early 1996 due to concern about residues on fresh market produce and possible exposure to infants and children. It was canceled for use on apples, apricots, cranberries, figs, green beans, lima beans, peaches, pears, plums, and strawberries.

In 1993, regulatory action was taken for methyl bromide under the Clean Air Act because of its adverse affect on the ozone layer in the upper atmosphere. Production and use will be terminated in 2001 and annual production until that date is limited to the 1991 level.

Pesticide Resistance

Pesticide resistance is most likely to develop when a pesticide with a single mode of action is used over and over in the absence of any other management measures to control a specific pest. If a weed, insect, or fungi species contains an extremely low number of biotypes resistant to the killing mode of the pesticide,

Table 3.2.7—EPA regulatory actions and special review status on selected pesticides used in field crops production, 1972 - June 1995

Pesticide	Regulatory action and date
Alachlor	Uses restricted and label warning, 1987; under EPA review for groundwater contamination
Aldicarb	Use canceled on bananas, posing dietary risk, 1992
Aldrin	All uses canceled except for termite control, 1972
Captafol	All uses canceled, 1987
Chlordimeform	All uses canceled, 1988. Use of existing inventory until 1989
Cyanazine	Manufacturers voluntarily phasing out production by 2000 but stock can be used until 2003
DDT	All uses canceled except control of vector diseases, health quarantine, and body lice, 1972
Diazinon	All use on golf course and sod farms canceled, 1990
Dimethoate	Dust formulation denied and label changed, 1981
Dinoseb	All uses canceled, 1989
EBDC (Mancozeb, Maneb,Metiram, Nabam, Zineb)	Protective clothing and wildlife hazard warning, 1982
Endrin	All uses canceled, 1985
EPN	All uses canceled, 1987
Ethalfluralin	Benefits exceeded risks, additional data required, 1985
Heptachlor	All uses canceled except homeowner termite product, 1988
Linuron	No regulatory action needed, 1989
Methyl Bromide	Annual production and use limited to 1991 levels with use to be terminated in 2001, 1993
Mevinphos	Voluntary cancellation of all uses, 1994
Monocrotophos	All uses canceled, 1988
Parathion	Use on field crops only, 1991; under EPA review with toxicological data requested
Propargite	Registered use for 10 crops canceled, 1996. Use for other crops remains legal
Toxaphene	Most uses canceled except emergency use for corn, cotton, and small grains for specific insect infestation, 1982
Trifluralin	Restrictions on product formulation, 1982
2,4-D (2,4-DB, 2,4-DP)	Industry agreed to reduce exposure through label change and user education, 1992

Source: USDA, ERS, based on information in EPA, 1995.

then those species that survive the pesticide treatment reproduce future generations containing the pesticide resistant trait. As this process repeats, the resistance trait multiplies and begins to account for a significant share of the species' population.

Although herbicide-resistant weeds have been documented since the early 1950's, their prominence in the last two decades has increased, resulting in management strategies that seek to minimize development of pesticide-resistant species. Rotating pesticides with different modes of action, applying mixtures of herbicides, reducing application rates, and combining mechanical or nonchemical control practices are some management strategies to reduce pesticide resistance (Meister Publishing, 1966). Resistance to triazine herbicides (atrazine, cyanazine, and simazine) is one of the more common weed-resistant problems in corn and sorghum. Farmers responding to USDA's Cropping Practices Survey in 1994 reported that 16 percent of the corn acreage had triazine-resistant weeds. To deter these and other weed resistance problems, producers reported that they alternated herbicides on the majority of corn, soybean, and cotton acreage. In recent years, producers also have reported using different active ingredients on each treated acre and lowering the application rates, both practices prescribed to deter herbicide resistance.

Similar to the development of weeds resistant to herbicides, the incidence of insects, mites, and disease-causing fungi species resistant to pesticides also causes producers to switch to different chemicals or pest controls (NRC, 1986). Once insect or fungi species develop resistance to one ingredient, the time required to develop resistance to other ingredients of the same chemical family is often much less. Over a short period of time, species resistant to an entire family of ingredients can develop and require a different mode of treatment. At least partially due to development of insecticide resistance, cotton insecticide families shifted from mostly organochlorines prior to the 1970's to organophosphates and carbamates and more recently to synthetic pyrethroids (Benbrook, 1996). Scouting to determine economic thresholds for treatments, alternating the use of pesticide families, and several other management strategies to combat resistance are now in use (see chapter 4.4, *Pest Management*).

New Pest Control Products and Technology

Each year, the EPA registers several new pesticides which producers may adopt if they offer improved pest control and are profitable. Acetachlor was granted conditional registration in 1994 as an herbicide for use on corn that would help reduce overall herbicide usage. The registration allows automatic cancellation if the use of other herbicide products is not reduced or if acetachlor is found in ground water. In 1995, about 23 million pounds of the new product were applied to 20 percent of U.S. corn acreage (table 3.2.3). The reduced pounds of alternative herbicides (alachlor, metolachlor, atrazine, EPTC, butylate, and 2,4-D) more than offset the pounds of acetachlor.

Other pesticide products have significantly affected the quantity of total use. For example, Imazethapyr, first registered for use on soybeans in 1989, has become the most widely used soybean herbicide in the United States. This herbicide, applied at less than 1 ounce per acre, often replaced trifluralin and other older products, applied at rates many times higher than imazethapyr.

Transgenic corn and cotton seeds have been marketed recently in the hope of reducing the need to apply insecticides. These seeds were bioengineered to produce Bt, a bacterial insecticide that can control cotton bollworms, European corn borer, and other insects when they eat plant tissues containing the Bt bacteria. Some scientists are concerned that the plants do not produce sufficient levels of pesticides and that the pest survival rates will speed up the evolution of pest resistance to Bt, including Bt sprays. Resistance management plans are often prescribed when these products are adopted (*Science*, 1996). About 13 percent of the U.S. cotton acreage was reported planted with this transgenic cotton seed in 1996. Bt, as a spray insecticide, was applied to 9 percent of the 1995 cotton acres, but only 1 percent of the corn acres.

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Glossary

Acute Risk Indicator—An indicator of the potential human and environmental health risk from an acute exposure to pesticides. An indicator value equal to 1 is the presence of 1 LD50 dose in the environment for 1 day. (See box, "Estimating Pesticide Impact or Risk," p. 124)

Amount of pesticide applied is the total pounds of all pesticide active ingredient (excluding carrier materials) applied. Because this sum can include materials applied at very different rates, differences in the amount applied do not necessarily represent differences in the intensity of the treatment or potential health and environmental risks.

Chronic Risk Indicator—An indicator of the potential human health risk from a chronic exposure to pesticides. An indicator value equal to 1 is the presence of 1 Reference Dose in the environment for 1 day.

LD50 dose—The constructed measure reflects the pesticide dose level (mg/kg of body weight) which results in 50 percent mortality of laboratory test animals. The LD50 values used in constructing the acute risk indicator relate to ingestion of the active ingredient (Oral LD50).

Land receiving pesticides represents an area treated one or more times with a pesticide material. Pesticide materials include products used to kill weed, plant, and fungi pests, as well as products used as growth regulators, soil fumigants, desiccants, and harvest aids.

Number of acre-treatments applied represents total number of ingredients applications made throughout the growing season. A single treatment containing two ingredients is counted as 2 acre-treatments as is 2 treatments containing a single ingredient.

Number of ingredients applied represents the total number of different active ingredients applied throughout the growing season on a field. It does not reflect repeat applications of the same ingredient during the production year.

Number of treatments applied represents the number of application passes made over a field to apply pesticides. One or more pesticide materials may be applied with each treatment. This measurement reflects labor and pesticide application equipment usage.

Pesticide, according to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), is "... any substance or mixture of substances intended for preventing, destroying, repelling or mitigating any insects, rodents, nematodes, fungi, or weeds, or any other forms of life declared to be pests; and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant." Types or classes of pesticides are:

- **Fungicides—**Control plant diseases and molds that either kill plants by invading plant tissues or cause rotting and other damage to the fruit before and after it can be harvested.

- **Herbicides**—Control weeds which compete for water, nutrients, and sunlight and reduce crop yields. Herbicides that are applied before weeds emerge are referred to *preemergence herbicides*. Preemergence herbicides have been the foundation of row crop weed control for the past 30 years. Herbicides applied after weeds emerge are referred to as *postemergence herbicides*. Postemergence herbicides are sometimes considered more environmentally sound than preemergence herbicides because they normally have little or no soil residual activity. Treatments applied prior to any tillage or planting to kill existing vegetation are referred to as *burndown applications*. Burndown applications are often a part of no-till systems.

- **Insecticides—**Control insects that damage crops. Also include materials used to control mites and nematodes.

- **Other Pesticides—**Include soil fumigants, growth regulators, desiccants, and other pesticide materials not otherwise classified.

Reference Dose—The constructed measure reflects the long-term safety/toxicity of pesticides to humans. It is measured as the no-observable-effect level of a pesticide ingredient multiplied by an uncertainty factor, which adds an additional safety factor in translating animal no-observable-effect levels to human no-observable-effect levels. The constructed value represents the "dose" (mg./lb. of body weight) which could be consumed daily over a 70-year life span by a person weighing 70 kg. without having adverse health effects.

Recent ERS Research on Pesticide Issues

"Phasing Out Registered Pesticide Uses as an Alternative to Total Bans: A Case Study of Methyl Bromide," *Journal of Agribusiness*, Vol. 15, No. 1, 1997. (Walt Ferguson, Jet Yee) This article examines how a phase-out strategy, in place of an immediate ban on all crops, would affect consumers and producers and still achieve much of the human health and environmental benefits of an immediate and total ban.

Agricultural Chemical Usage, 1995 Fruits Summary (Ag CH1 96), July 1996. This report continues a series of biennial reports of chemical use on most fruit commodities produced in the United States. This summary contains state estimates of primary nutrients and pesticide active ingredients use in the on-farm production of these commodities.

Agricultural Chemical Usage, 1995 Field Crop Summary. (Ag CH 1 96), March 1996. This report continues a series of annual field crop summaries since 1990 that estimate on farm fertilizer and pesticide use on U.S.-produced corn, cotton, potatoes, soybeans, and wheat. This summary contains State estimates of the primary nutrients and pesticide active ingredients used in the production of these commodities.

Pesticide Residues, Reducing Dietary Risks. AER-728, Jan. 1996. (Fred Kuchler, Katherine Ralston, Laurian Unnevehr, Ram Chandran) New data on pesticide residues, food consumption, and pesticide use are used to analyze the sources of consumers' dietary intake of pesticide residues and the benefits of research to develop safer alternatives to pesticide use. This study reports that canceled but persistent chemicals appear among the highest risk indicators; postharvest uses account for the largest share of dietary intake of residues; residue levels vary among domestic and imported commodities; and consumption patterns, especially those of children, influence risks from pesticide residues.

Regulation, Innovation, and Market Structure in the U.S. Pesticide Industry. AER-719, 1995. (Michael Ollinger, Jorge Fernandez-Cornejo) This report examines how EPA regulation affects new chemical pesticide registrations, new chemical pesticide safety and use, industry composition, and technology choice.

"The Effect of Feedgrain Program Participation on Chemical Use." *Agricultural and Resource Economics Review*, Oct. 1995. (Marc Ribaudo, Robbin Shoemaker) This journal article addresses whether commodity programs create economic incentives and conditions that result in higher per-acre use of chemicals than would occur under free-market conditions. The feedgrain program appears to provide incentives for participants to apply more fertilizer and herbicides than nonparticipants.

Agricultural Chemical Usage, 1994 Vegetable Summary. (Ag CH1 95), July 1995. This report continues a series of biennial reports of chemical use on most vegetable commodities produced in the United States. This summary contains State estimates of primary nutrients and pesticide active ingredients used in the on farm production of these commodities.

Pesticide and Fertilizer Use and Trends in U.S. Agriculture. AER-717, May 1995. (Biing-Hwan Lin, Merritt Padgitt, Len Bull, Herman Delvo, David Shank, Harold Taylor) Trends in fertilizer and pesticide use since 1964 along with economic analysis of factors influencing agricultural chemical use are contained in this report.

Adoption of Integrated Pest Management in U.S. Agriculture. AIB-707, Sept 1994. (Marc Ribaudo, Robbin Shoemaker) This report summarizes information on the extent of adoption of integrated pest management (IPM) techniques in the production of fruits, vegetables, and major field crops. Levels of IPM vary widely among crops and regions, but about half of all fruit, vegetable, and major field crop acreage uses some IPM techniques.

Atrazine: Environmental Characteristics and Economics of Management. AER-699, 1994. (Marc Ribaudo, A. Bauzaher) This report presents the costs and benefits of an atrazine ban, a ban on pre-plant and pre-emergent applications, and a targeted ban to achieve a surface water standard. A complete atrazine ban is hypothesized to be the costliest strategy, while the targeted strategy is the least costly.

Economic Effects of Banning Methyl Bromide for Soil Fumigation. AER-677, 1994. (Walt Ferguson, A. Padula) This report estimates the consequences for producers and consumers of banning the use of methyl bromide for agricultural uses.

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